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(54) A COMBINATION ENGINE AND AIR COMPRESSOR

(71) I, TAKAHIRO UENO, of 5-11, 4-Bancho, Wakayama City, Japan, a Japanese citizen, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a combination internal combustion engine and air compressor, for example, one mounted on a vehicle to propel the same.

The invention consists in a combination as claimed in claim 1. Embodiments of the invention may include any of the further features claimed in claims 2 to 20

The present invention may be embodied in an engine mounted on any vehicle such as an automobile, a street car, a ship, an aeroplane and the like, which engine could be any internal combustion engine such as, for example, a petrol or mixture-compression engine, a Diesel engine, a Wankel engine.

In the following description of embodiments, only a 4-stroke petrol or mixture compression engine will be described as this kind of engine is particularly difficult to operate as an air cimpressor and the description will thus provide for easy understanding of a range of embodiments of the present invention.

A plurality of cylinders of an engine combination embodying the invention may be divided into two sets to obtain separate operation of each set of cylinders and the actions of said sets may be combined in various manners such as all the cylinders effecting an engine action, one set of cylinders effecting an engine action with the other effecting an air compression action, all the cylinders effecting an air compression action, all the cylinders effecting an air compression action, so that a single engine can be used for many applications. Such an engine may be mounted on a vehicle so that propulsion of the vehicle is improved, and particularly in the case of the engine combination being used for an engine-brake, fuel expense is saved and environmental pollution is prevented.

Compressed air obtained during the time a vehicle is being braked can be used for starting the engine, operating the engine as an air-motor, or operating a vacuum suction device for braking the vehicle.

The embodiments described below relate *inter alia* to an engine provided with double cam shafts and/or an engine supercharged with compressed air obtained at the time of braking or at some other desired time. They further provide constructions for braking, stopping, air-starting and normally rotating, and starting and continuing reverse rotation of such an engine in the case of said engine being applied in a ship.

Engines embodying the present invention are, even in the case of a single cylinder engine, able to be operated as an air compressor or an air motor.

An engine embodying the present invention may be a known engine which comprises one or more cylinders, a piston adapted to slide in each of said cylinders, an inlet valve and an exhaust valve for opening and closing each of an inlet port and an exhaust port provided on the upper portion of said cylinder, two cam shafts each comprising a cam for operating said inlet valve or said exhaust valve respectively, a transmission for transmitting rotation of a crank shaft to both of said cam shafts, an air supply means connected to said inlet port for supplying air and fuel thereto and a means connected to said exhaust port for guiding exhaust gas therefrom.

For effecting an air compression action, the engine may be provided with: an air supply means for supplying one or more chambers with air without fuel, an air take-

out means for taking out at a desired time air compressed within said chambers, a tank for storing said compressed air, said tank being connected to an exhaust pipe constituting a part of said air take-out means, an operating means for operating at a desired time said air supply means and said air take-out means. Said air supply means may be a means for supplying said chambers with air only by stopping fuel-supply through a magnet valve into a carburettor or changing passages of an inlet pipe, and includes a means for timing the inlet and the exhaust valves for an air compression action. Said operating means may be a means for operating at a desired time magnet valves of the air supply means and the air take-out means. The air take-out means may be a means adapted to change the exhaust passage by means of a magnet valve thus allowing storage of compressed air.

In one embodiment an engine is changed over to effect an air compression action by changing the rotation angle of a cam shaft for an exhaust valve with respect to a crank shaft and by rotating the cam shafts for an inlet and an exhaust valve at the same rotational frequency as the crank shaft.

In another possibility an engine is changed over to effect a compression action or a no-load operation action by stopping fuel-supply to half a plurality of chambers and supplying them with air only, thereby saving fuel expense and reducing atmospheric pollution.

Another possible feature is for an engine to be changed over to serve as an air compressor, by adapting it to suck in air through an exhaust port, by changing the angular relationship of a cam shaft for an exhaust valve with respect to a crank shaft, and by adapting it to exhaust air by means of an automatic valve provided on the cylinder-head.

A further possible feature is to provide two pairs of transmissions for transmitting rotation of a crankshaft to respective cam shafts one pair being for an engine action with the other being for an air compression action to allow an inlet and an exhaust valve to suck in air.

A further possible feature is to divide a plurality of cylinders into two sets, the first set of cylinders being operated to effect an engine action and the second set for a compression action, and high pressure air obtained by said compression action set being reduced in pressure and used for supercharging the first set thereby increasing the driving power of the engine.

A further possible feature is for the engine combination to drive a compressed air machine or device by compressed air obtained in an air compression action section of the combination and be adapted to supply the low pressure compressed air after use and the residual air in the air compression action section for supercharging an engine section of the combination, thereby effectively using compressed air and minimizing noise due to the compressed air machine or device.

A further possible feature is to inject compressed air through a residual gas exhaust port to rotate the engine in the normal direction, and by changing valve-timings of inlet, exhaust and residual gas exhaust valves to rotate the engine in the reverse direction.

A further possible feature is to adapt the engine so that at the time of change-over from normal rotation to reverse rotation, the engine is braked by changing an engine action into an air compression action and absorbing kinetic energy from normal rotation of the engine and use this to start reverse rotation so that the engine responds quickly and reverse rotation is obtained substantially without waste of kinetic energy.

A further possible feature is to inject high pressure air through an exhaust port of the engine so that the engine is actuated to rotate in the normal or reverse direction.

Reference will now be made by way of example to the accompanying drawings, in which:—

Fig. 1 is a schematic plan view for illustration of the first and the second embodiments of the present invention;

Fig. 2 is a section of a cylinder of an engine of the first embodiment of the present invention;

Fig. 3 is a section of the second embodiment for illustration of a cylinder of an engine of the second embodiment;

Fig. 4 is a schematic view of inlet and exhaust passages of the second embodiment;

Fig. 5 is a sectional plan view for illustration of the third embodiment of the present invention;

Fig. 6 is a front view for illustration of a cam for an inlet valve and a cam for an exhaust valve of the first set of cylinders of the third embodiment;

Fig. 7 is a section taken along line VII-VII of Fig. 6;

Fig. 8 is a perspective view for illustration of modifications of cams for inlet and exhaust valves of the first set of the cylinders of the third embodiment;

Fig. 9 is a front view for illustration of cams for inlet and exhaust valves of the second set of the third embodiment;

Fig. 10 is a section taken along line X-X of Fig. 9;

Fig. 11 is a section taken along line XI-XI of Fig. 9;

Fig. 12 is an explanatory view of inlet and exhaust passages of the engine of the

third embodiment;

Fig. 13 is a section for illustration of a cylinder provided with an air port and an air port valve of the engine of the fourth embodiment of the present invention;

Fig. 14 is a schematic front view of a cam for operating a residual gas exhaust port;

Fig. 15 is an end view taken along line XV-XV of Fig. 14;

Fig. 16 is an end view taken along line XVI-XVI of Fig. 14;

Fig. 17 is a schematic front view of a cam for operating an inlet valve;

Fig. 18 is an end view taken along line XVIII-XVIII of Fig. 17;

Fig. 19 is an end view taken along line XIX-XIX of Fig. 17;

Fig. 20 is a schematic front view of a cam for operating an exhaust valve;

Fig. 21 is an end view taken along line XXI-XXI of Fig. 20; and

Fig. 22 is an end view taken along line XXII-XXII of Fig. 20.

Referring to Figs. 1-4, a combination engine and air compressor embodying the present invention is shown, by way of example, in the form of an engine provided with double overhead cam shafts and having adaptive features to enable operation of the engine as an air compressor. In the particular embodiments described below, while it is appreciated that a chamber is defined in a cylinder the terms "chamber" and "cylinder" are used interchangeably where no confusion will arise.

An engine 1 having the features of the combination defined in Claim 1, is provided with a known transmission 4 for transmitting rotation of a crank shaft 8 to cam shafts 6, 7 for operation in said first mode to give engine action, and, besides, another transmission 5 for transmitting rotation of of the crank shaft to the cam shafts for operation in said second mode to give air compression action, further, a means for changing over from one to the other of said two transmissions and correspondingly changing inlet and exhaust passages and such other features as required. Each of said transmissions 4, 5 is adapted to operate cam shaft 6 for inlet valves and cam shaft 7 for exhaust valves.

An engine provided with double overhead cam shafts is usually intended to run at a high rotational speed. In such an engine the valve opening angle produced by the cam is very large e.g. 140° and the overlapping angle is about 50°. Said transmission 5 is a means for eliminating such an overlapping angle and for changing valve-timing for both inlet and exhaust valves to a desired timing, e.g. opening said exhaust valve 180° after closing said inlet valve.

Said transmission 4 for an engine action comprises sprockets 9, 10, 11 which are rotatably fitted to a crank shaft 8, a cam shaft 6 and a cam shaft 7 respectively, electromagnetic clutches 12, 13, 14 for engaging each of said sprockets 9, 10, 11 with the corresponding shaft 8, 6, 7 at a predetermined position and a chain 15 for simultaneously rotating said sprockets 9, 10, 11 in one direction. By passing electric current through said magnetic clutches 12, 13, 14, said cam shafts 6, 7 and brought into operation, the angular relationship of said cam shafts with repect to said crank shaft 8 being the same as that of the corresponding cam shafts of a conventional engine. In other words, the transmission 4 for an engine action provides the cam shafts 6, 7 with motion to effect valve-timing for an engine action.

Similarly to the transmission 4 for an engine action, the transmission 5 for an air compression action comprises sprockets 16, 17, 18, electromagnetic clutches 19, 20, 21 and a chain 22.

Two embodiments can be referred to here for achieving an air compression action of the engine 1. In the first embodiment, as shown in Fig. 2, compressed air is taken out through an exhaust pipe 25 of the engine 1, while in the second embodiment, as shown in Fig. 3, an air port 28 is formed between an inlet port 26 and an exhaust port 27 and compressed air is taken out through an automatic exhaust valve 29 provided in said air port 28.

Referring to Fig. 2, the first embodiment is now described below. The sprocket 16 of the transmitting means 5 has the same diameter as the sprockets 17, 18, and is adapted to rotate each of the cam shafts 6, 7 with the same rotational frequency as that of the crank shaft 8. Thereby, the inlet and exhaust valves are opened and closed once per rotation of the crank shaft 8, so that the 4-stroke engine is given the valve-timing of a 2-stroke air compressor. Said valve timing is controlled by means of the cam shafts, themselves controlled by the electromagnetic clutches 20, 21. The electromagnetic clutch 20 is arranged to engage the sprocket 17 on the cam shaft 6, so that the opening of the inlet valve occurs at a time a little delayed with respect to the corresponding timing in an engine action and after the piston in the cylinder has commenced to move downwards from the top dead centre.

On the other hand, the magnetic clutch 21 provided on the cam shaft 7 for the exhaust valve 32 is arranged to engage the sprocket 18 on the cam shaft 7 so that the exhaust valve 32 is closed when the piston reaches the top dead centre.

Further, the engine of the first embodi-

ment may be so adapted that the difference between an engine action and an air compression action insofar as the valve timing is concerned is made to consist only in the rotation frequencies of the cam shafts, by providing only two electromagnetic clutches 12, 19 and fixing the sprockets 11, 13, 17, 18 on the corresponding cam shafts 6, 7.

An inlet pipe 24, which communicates with an inlet port 26, is connected to a pipe 35 which leads to an air tank T for storing compressed air obtained by the air compression action of the engine, said air tank T being able to store therein air at a pressure of 8-16 kg/cm² in the case of making the engine serve as a 1-stage air compressor, and 20-50 kg/cm² in the case of making the engine serve as a 2-stage air compressor and in the case of the engine being a Diesel engine.

Said pipe 35, and another pipe of which only an unreferenced stub is shown in Fig. 2, are connected through a 3-way magnet valve 36 to said inlet pipe 24, to supply therethrough the inlet port 26 with a fuel and air mixture (the stub), air only (the stub) or high pressure air (pipe 35). The 3-way magnet valve 36 is operated by an operating means (not shown).

A pipe 37 communicating with the air tank T is connected through a 3-way magnet valve 38 (also operated by an operating means (not shown), to the exhaust pipe 25 communicating with the exhaust port 27.

A check valve 39 is provided in said pipe 37 so that high pressure air in the air tank T is prevented from flowing to the exhaust port.

In the case of the engine having an air compression action, due to operating the operating means, the 3-way magnet valves 36, 38 are so opened that air flows in the direction of the arrows marked X, and by demagnetizing the electromagnetic clutch 12 and magnetizing the electromagnetic clutch 19, the valve timing is converted into that for the air compression action.

Air having passed through a carburettor without admixture of fuel is supplied through the inlet port 26 into the chamber shown (unreferenced), and compressed therein and then supplied through the exhaust port 27 and 3-way magnet valve 38 into the air tank T to be stored therein.

Besides such an air compression action, the engine of the first embodiment of the present invention provided with the above-mentioned structure can also be operated as an air motor for driving a crank shaft.

In the case of the engine being operated to rotate in the normal direction as an air motor, 3-way magnet valves 36, 38 are opened so that air flows in the direction of the arrows marked Y by operating the operating means and the inlet and exhaust valves are operated with the same timing as that of compression action.

When the flow takes the direction of the arrows marked Y through the 3-way magnet valves 36, 38 compressed air (having a pressure of 8-16 kg/cm² in the case of a petrol or mixture compression engine or 20-50 kg/cm² in the case of a Diesel engine) from the air tank T flows to the inlet port 26, and is allowed into the chamber 2 by opening inlet valve 31, the compressed air then pushing down the piston. Potential (compression) energy of the high pressure air is consumed in operating the piston, and the air is then discharged through the exhaust pipe 25 by opening exhaust valve 32.

On the other hand, in the case of operating the engine to rotate in the reverse direction as an air motor, the 3-way magnet valves 36, 38 are opened for flow in the reverse direction to the arrows marked X (valve 39 being then suitably arranged to allow this) and compressed air is fed through the pipe 37 and the exhaust port 27 into the chamber and then discharged through the inlet pipe 24.

Referring to Fig. 3, the second embodiment will now be described.

Similarly to the first embodiment, the magnet clutch 20 of the transmission 5 is arranged to engage the sprocket 17 with the cam shaft 6 so that the inlet valve 31 is open while the piston is descending from the top dead centre.

The sprocket 18 of the cam shaft 7 likewise opens the exhaust valve 32 while the piston is descending from the top dead centre at the time corresponding to the explosion stroke of a 4-stroke (engine) action, said sprocket 18 being engaged with the shaft 7 by the magnet clutch 21 at the position suitable for such valve-opening.

The sprocket 16 has a diameter of half the diameter of the sprocket 17 or 18. In an air compression action, the inlet and exhaust valves are alternately opened once per two rotations of the crank shaft 8 while the piston is descending. However, by making the gear ratio between the sprocket 16 and each of the sprockets 17, 18 1:1, thus rotating each cam shaft 6, 7 once per rotation of the crank shaft 8, the inlet and exhaust valves can be simultaneously opened at times corresponding to the suction stroke and explosion stroke of a 4-stroke (engine) action, so that an increased amount of air can be sucked in.

In an air compression action, the exhaust valve port 27 and pipe 25 are supplied with air only through a special suction passage, mentioned below, in substitution for the exhaust passage used for engine action.

The automatic exhaust valve 29 is provided on each cylinder head of the engine 1, adapted to be closed by means of an oil

pressure, air pressure or electric means (of which a pressurizing means 44 is shown) in an engine action and to automatically exhaust air compressed to a predetermined pressure in the cylinder in an air compression action, an exhaust port 28 of said automatic exhaust valve being connected through a duct 45 to the air tank T. As said automatic exhaust valve 29, for example, there can be employed an air charging valve.

Referring now to Figs. 1 and 4, operation and inlet and exhaust passages of the second embodiment are described below. During an engine action, in the engine 1, the transmission 4 for an engine action is operated, air-fuel mixture sucked through a carburettor 40 and the inlet pipe 24 into each of the cylinders is combusted and then discharged through the exhaust pipe 25 and an exhaust gas port 41.

On changing over the engine from an engine action to an air compression action, the magnetic clutches 12, 13, 14 are demagnetized and instead thereof the magnetic clutches 19, 20, 21 are magnetized to change the angular relationship between the crank shaft and the cam shafts rotation angle and/or speed of the cam shafts 6, 7 for the inlet and exhaust valves 31, 32, a 2-way magnet valve 42 is opened, then a 2-way magnet valve 43 is closed, and also, a magnet valve (not shown) for closing a fuelling pipe to the carburettor 40, so that the inlet passage is changed, and the pressure of the pressurizing means 44 which has been holding closed the automatic exhaust valve 29 by oil or air pressure is released. In such a state, air having passed through the carburettor 40 and the inlet and exhaust pipes 24, 25 is sucked through the inlet and exhaust ports into the cylinder and (after closing inlet and exhaust valves 31, 32) is compressed until the predetermined pressure is obtained, and then exhausted through the automatic exhaust valve 29, a manifold (comprising ducts 45) and a check valve 46 into the air tank T, to be stored therein.

In the second embodiment, a magnetic clutch is provided at the position of each sprocket in order to decrease rotation noise and torque consumption of sprockets out of use during an action. Three clutches are sufficient for such purpose. The rotary positions of said sprockets may be variously changed. Further, by dividing both of the cam shafts into two in a proper proportion (for example, 3:3 in the case of 6 cylinders), and providing a magnetic clutch (as shown in phantom line in Fig. 1) at such divided position for free connection of the two parts of each shaft with each other, a part of the engine (the left three cylinders in Fig. 1) can be operated with an engine action with the other part (the right three cylinders in Fig. 1) operated with an air compression action. In such a case, the inlet and exhaust passages are suitably changed.

The structures of the first and second embodiments can be applied to all engines with double cam shafts of either a side valve type or an overhead valve type, and also to both mixture compression engines and Diesel engines.

Further, an engine provided with double overhead cam shafts is usually intended to run at a high rotational speed, it is designed with small inertial mass, so that in the case of the engine being operated as an air compressor even though the inlet and exhaust valves are opened and closed twice as often as the opening and closing operations occur in an engine action, jumping, bouncing, surging or the like is prevented.

Referring now to Figs 5-12, the third embodiment of the present invention is shown for illustration of operation of an engine mounted on a vehicle for an air compression action.

An engine 51 is so adapted that only the right-hand (as seen in Fig. 5) three cylinders are operated for an air compression action by supplying them with air only.

The engine 51 operates in four ways — all cylinders being operated for an engine action, the left-hand (as seen in Fig. 5) three (the first set of) cylinders 52 being for an engine action with the right-hand three (the second set of) cylinders 53 being for an air compression action, said first set being operated as an engine to be supercharged with said second set as a supercharger for supercharging said first set, and the first set being operated as an engine with the second set in a no-load (see below) state.

A cam shaft 54 of said first set of cylinders 52 is adapted to be axially moved by a three-step means for changing-over the position of the shaft while the came shaft 55 of the second set 53 is axially moved by a two step change-over means. Further, the end portion of the cam shaft 54 adjacent to said cam shaft 55 is cylindrical and rotatably and slidably supported through a bearing by the engine body. On said cylindrical end portion of the cam shaft 54, the cam shaft 55 is rotatably and slidably supported.

Referring to Figs. 6, 7, there are shown a cam 57 for an inlet valve and a cam 58 for an exhaust valve provided on the cam shaft 54 of the first set 52.

The cam 57 for the inlet valve is provided with a normal cam section 59 for normal valve overlapping angle (see below) and a supercharging cam section 60 for increased overlapping. In other words, said supercharging cam section 60 is provided for the purpose of making an overlapping angle relatively large so as to open the inlet valve before the exhaust valve is closed, for blowing away residual gas in the clear-

ance volume at the end of the exhaust step by means of newly introduced air so that the latter replaces the former in order to increase the amount of fresh air in the cylinder each cycle, to increase the mean effective pressure on combustion and thus increase the power.

The cam 58 for the exhaust valve is also provided with a normal cam section 61 and a supercharging section 62. Said four cam sections 59, 60, 61, 62 provide different valve-timings respectively, but, apart from this, all are substantially in the same form as the supercharging cam section 60 shown in Fig. 7.

Referring to Fig. 8, there is shown a modification of the cam 57 for the inlet valve or the cam 58 for the outlet valve, in which a normal cam section 59, 61 is adjacent to a supercharging cam section 60, 62.

Referring to Figs. 9-11, there are shown a cam 65 for the inlet valve and a cam 66 for the exhaust valve provided on the cam shaft 55 for said second set of cylinders.

The cam 65 for the inlet valve comprises, as shown in Fig. 10, an engine action segment 65E (with the same sectional form as said normal cam section 59) which is adapted to open the inlet valve once per revolution of the cam shaft, and an air compression action segment 65C adapted to open the inlet valve twice per revolution of the cam shaft.

The cam 66 for the exhaust valve is provided with an engine action segment 66E, a 1-stage compression action (see below) segment 66C, a 2-stage compression action (see below) segment 66S and a no-load action (see below) segment 66U, and only the engine action segment 66E operates the exhaust valve once per revolution of the cam shaft while the others operate the same twice per revolution of the cam shaft. The engine action segment 66E provides the same action as said normal cam section 61, and the 1-stage air compression action segment 66C opens the exhaust valve of the second set a little before the end of the corresponding compression and exhaust strokes of the engine action of the first set of cylinders, to exhaust high pressure compressed air. The 2-stroke compression action segment 66S opens the exhaust valve after a compression and an exhaust action of the engine start thus exhausting low pressure compressed air. The no-load action segment 66U opens and closes the exhaust valve to allow flow of air at times which overlap the opening and closing operations of the inlet valve.

It is an important feature of this embodiment that the action carried out for the supply of air by the second set of cylinders is divided into three stages or manners of operation: 1-stage compression, 2-stage compression and zero compression (zero supply of air). The 1-stage compression action segment 66C produces high pressure air (8-10 kg/cm^2 in the case of a petrol or mixture compression engine and 8-16 kg/cm^2 in case of a Diesel engine) used for operating a compressed air machine such as a cooler. The 2-stage compression action segment 66S produces high pressure air similarly to the 1-stage compression segment but but compressing air in two stages (see below) reduces the load on the first set 52 upon starting the engine in order to smooth the transition to a 1-stage compression action. The no-load action segment 66U causes the engine to drive the vehicle by means of an engine action of only the first set 52 thus saving about 50% of fuel expense.

Further, high pressure air produced by the second set of cylinders is supplied to the first set as supercharging air through a pressure adjusting valve or after use in a compressed air machine, and then the required increase in power of the engine action of the first set is controlled, so that a compression action of the second set is carried out with sufficient driving power.

The middle portion between the engine action segment 66E and the 1-step compression action segment 66C can keep the exhaust valve closed, and therefore can be used instead of the no-load action segment 66U.

The operation of the engine 51 with the abovementioned construction and exhaust passages is described below with reference to Fig. 12.

In the case of making the second set of cylinders effect an air compression action when the vehicle is slowing down the segments are so arranged that the inlet and outlet valves of the first set 52 are driven by the normal cam section 59, 61 while the inlet valve of the second set 53 is driven by the compression action segment 65C and the outlet valve thereof is driven by the 2-step compression action segment 66S.

When chambers X, Y, Z of the first set 52 are actuated as an engine, a piston of the second set 53 connected to the same crank shaft operates so that air is introduced through the inlet ports 26A, 26B and the inlet pipe 24 into the chambers, compressed therein substantially to 4 kg/cm^2, then exhausted through exhaust ports 27A, 27B and introduced through the exhaust pipe 25 and a duct 70 into a chamber C. The air introduced into the chamber C is compressed substantially to 8 kg/cm^2, then exhausted through an exhaust port 27C of the chamber C to be stored at once in the air tank T. At that time, a 2-way magnet valve 71 is open with a 2-way magnet valve 72 being

closed and 3-way magnet valves 73, 79 being open in the X direction.

When the turning power of the engine increases as it comes to a constant speed operation, the cam shaft 54 is displaced so that the inlet and exhaust valves of the first set are operating by means of the supercharging cam segments 60, 62, and the cam shaft 55 is displaced so that the exhaust valve of the second set 53 is operating by means of the 1-step compression action segment 66C, and further the 2-way magnet valve 71 is closed, the 2-way magnet valve 72 is open and the 3-way magnet valve 73 is open in the Y direction.

In this state, air introduced into the chambers A, B, C is compressed at once substantially to 8 kg/cm^2 and supplied to the air tank T. An air take-out pipe 74 is connected to the tank T, so that by opening the 3-way magnet valve 78 in the X direction, compressed air is supplied into a compressed-air machine 75 such as one providing cooling action. From compressed-air machine 75 adapted to exhaust used air through one port used low pressure compressed air is lead through a return pipe 76 and introduced into the inlet pipe (ahead of the carburettor) of the first set 52 to be used for supercharging. Preferably, a surge tank or other smoothing device is provided on said pipe 76 for smoothing the flow of intermittently discharged air. Further, though not shown, the connected portion between the pipe 76 and the inlet pipe of set 52 is so adapted that blow back against the air flow is prevented. This can also be done by opening the said port only for flow in the direction of gas flowing through the return pipe 76 into the inlet pipe of set 52.

Numeral 77 indicates a pressure adjusting valve. In the case of using high pressure air in the tank T directly for supercharging by opening the 3-way magnet valve 78 in the Y direction, the pressure of said air is suitably lowered by means of said valve 77.

Said tank T can contain air compressed to a pressure of 8 kg/cm^2. In the case of air having a pressure above 8 kg/cm^2, the pressure thereof is reduced for the purpose of its storage in the tank.

In the case of making the engine drive the vehicle the 2-way magnet valves 72, 80 are opened, the 2-way magnet valve 71 is closed and the 3-way magnet valves 73, 79 are opened in the Y direction. It is so arranged that the carburettor is fuelled and at the same time the inlet and exhaust valves of the first set are operated by the normal cam sections 59, 61 while the inlet and exhaust valves of the second set are operated by the engine action segments 65E, 66E.

Mixture is supplied from the carburettor 40 to all the cylinders and combusted in the chambers to become exhaust gas, and then exhausted through the exhaust port 41. In this case, the inlet pipe can be supercharged directly, or through the compressed-air machine, from the tank T.

When the vehicle is subject to idle rotation and cruising, it is not necessary for all the cylinders to effect an engine action, but the first set alone can have an engine action with the second set being in no-load operation. In such a case, the inlet and exhaust passages of the first and the second sets of the engine 51 are arranged for said normal (engine) and air compression actions respectively, while the inlet valves of the second set are operated by the compression action segment 65C with the exhaust valves thereof operated by the no-load action segment 66U. Combustion action takes place in the chambers of the first set, but only air is taken into the chambers of the second set without either combustion or compression action. However, such air flow takes place only in the case of the 3-way magnet valve 79 being opened in the Y direction. If it were opened in the X direction air would not flow freely through the valve 79 because of the pressure in tank T (and there would be compression).

Further, at the time of reduction of the vehicle speed, the second set is made to effect an air compression action using kinetic energy of the vehicle to produce compressed air substantially without consuming fuel.

In said embodiments all cylinders are adapted to effect an engine action, but there may be included some cylinders adapted not to effect an engine action but to take only an air compression action (including 2-step compression action) and an air motor action. Further, at the time of starting and acceleration of the vehicle, half of the chambers may be made to effect an air motor action and the whole or a part of the air used for said air motor action and the whole or a part of the air used for said air motor action may be used for supercharging in an engine action so as to make the vehicle travel, while during travel of the vehicle at a constant velocity half the cylinders may be made to undergo no-load operation.

For the purpose of increasing durability of the engine, each cylinder is made to effect an alternative action so that a chamber having effected an engine action is made to effect a compression action with a chamber that has effected a compression action being made to effect an engine action, after fixed intervals, for example, after every 4000 km travel of the vehicle.

Further, in a particular embodiment, by connecting a displacement compressor to

an engine for propelling the vehicle, said engine is made to effect only an engine action with said displacement compressor made to effect an air compression action (including no-load operation) or an air motor action. In this case, the engine may have any number of cylinders, and the displacement compressor is selected to have a volume in correspondence with the power of said engine. As a displacement compressor, there can be used an engine adapted to act as an air compressor.

Further, during propulsion of a vehicle having thereon an engine with 4, 6, 8 or 12 cylinders, by making half of the cylinders effect an engine action to propel the vehicle, while making the remaining cylinders effect an air compression action to store compressed air obtained therefrom in the tank, said tank is cooled using air flow caused by travel of the vehicle. Also, the compressed air thus cooled can be made to expand in the tank through an expanding valve and be utilized for cooling the inside of the vehicle. The exhaust air from said cooler can be used for supercharging the engine action section. In the case that the tank is filled with compressed air obtained by a compression action of the engine, the compression action section is subject to no-load operation, the corresponding change-over being easily effected by, for example, operating a valve in a fluid line for controlling an exhaust valve. Consequently, it is not necessary always to rotate the engine to operate the cooler, and to provide the cooler with an air compressor. As a result, fuel and resources can be saved. This system is effective when applied to engines, especially rotary engines which consume a large amount of fuel thus tending to cause environmental pollution. According to this system, exhaust gas after being used in compressed air machines and apparatus is not dispersed in the atmosphere but is introduced into the engine section, so that exhaust gas noise can be prevented by the resulting masking effect.

Further, in the case that after braking the vehicle (e.g. said braking being effected by a finger-brake system) by operating the second set of cylinders as a compressor brake or an ordinary engine brake, the vehicle is immediately accelerated, the second set is supplied with compressed air so as to effect an air motor action and then the first set is made to effect an engine action. Even in this case, it is possible to prevent ill effects being felt during travelling which are apt to be caused by fuel-cuts in vehicle operation using a conventional engine.

Usually, a supercharger is used for increasing the maximum power of an engine. However, a supercharger incurs great expense, so that it is rarely used in a petrol or mixture compression engine. On the contrary, according to the present embodiments high pressure air obtained by an air compression action of an engine is reduced in pressure and cooled, and used for supercharging the engine section, thereby affording a reduction in the expense incurred.

Such a mild supercharging is extremely effective and can contribute to prevention of atmospheric pollution which tends to be caused at the time of increasing the power of engine for starting up or acceleration.

Further, in the case of an engine with a supercharger, for example, a Diesel engine, the supercharger may be supplied with air at low temperature and a low pressure above atmospheric, so that power is multiply increased by the combined effect.

In the case of an engine with double overhead cam shafts as described in the first embodiment, each cam has a lobe shaped to produce a large overlap angle and therefore is suitable for supercharging, so that a separate means is not required to be mounted thereon for supercharging, and so that the required frequency of frequent gear-changing may be reduced during high power operation.

Figs. 13 to 22 show the fourth embodiment of the present invention that is an engine wherein the valve timing of the inlet and exhaust valves is changed so that the engine can serve as an air-compressor and a third air port and valve are provided between the inlet and exhaust valves for exhausting the high pressure residual air whilst the engine is effecting compressor action, and further high pressure air is supplied through the third air port to rotate the engine per se normally or reversely. This embodiment is particularly useful for marine vessel engines.

Numeral 82 indicates a residual gas exhaust port to be used in the case of making the engine effect an air compression action, in which port there is provided a valve 83 for opening and closing said residual gas exhaust port 82.

In a manifold 84 that is connected to said port 82, one branch 85 is connected to either free air or a supercharger, while the other branch 86 is connected to a high pressure tank that contains compressed air at approximately 20 to 50 kg/cm^2 (possibly, in the other previously mentioned case, 8-10 kg/cm^2). On the pipe 86 there are provided an opening and closing valve 87 for supplying high pressure air from the tank T to the exhaust port 82, and a check valve 88 for supplying high pressure air from the exhaust port 82 to the tank T. The compressed air in said tank has been obtained by the compressor action of the engine, though such air can be alternatively supplied from the exterior (outside the engine)

through an inlet (not shown) of pipe 86. A three-way magnet valve 89 is provided at the branching point of the manifold 84, which is used to switch the air flow between branches 85 and 86.

Figs. 15, 16, 18, 19, 21, 22 show cam segments in relation to a common reference cycle in which the first (upper right hand), second (upper left hand), third and fourth quadrants correspond respectively in normal rotation to the intake, exhaust, explosion and compression strokes and in reverse rotation to the exhaust intake, compression and explosion strokes, with the engine action segments being shown in full lines and the compression action segments in phantom lines, and the pair of Figs. relating to each cam showing that the respective segments are symmetrically located about the (vertical) line joining the top dead centres. In practice, the reverse rotation segments shown in Figs. 16, 19, 22 are rotated 180° relative to the normal rotation segments shown in Figs. 15, 18, 21, as is seen in Figs. 14, 17, 20.

Figs. 14 to 16 show a driving cam 91 for the valve 83, the cam comprising a cylindrical segment 92 for engine action which does not drive the co-acting tappet, a normal rotation starting segment 93 which drives the tappet at a time approximately corresponding to the starting of the explosion stroke in the engine action, a residual air exhaust segment 94 which drives the tappet for exhausting the residual air during the time the engine is effecting normally rotating compressor action, a reverse rotation starting segment 95 which drives the tappet at a time approximately corresponding to the end of the compression stroke during the time the engine is effecting normal engine action, and a residual air exhaust segment 96 which drives the tappet to open valve 83 during the time the engine is effecting reversely rotating compressor action.

Said 3-way electromagnetic valve 89 opens in the direction of the arrow X to connect the pipe 86 with the air port 82 only when the tappet of the valve 83 is coactive with the normal rotation starting segment 93 and the reverse rotation starting segment 95, while otherwise it opens in the direction of the arrow Y.

The cam 101 for the intake valve 31 comprises, as shown in Figs. 17 to 19, a normally rotating engine action segment 102, a normally rotating compressor action segment 103 which drives the co-acting tappet at a time approximately corresponding to the intake and explosion strokes in the engine action, a reversely rotating engine action segment 104 which opens the inlet valve 31 at a time corresponding to the exhaust stroke in normal rotation of the engine, a reversely rotating compressor action segment 105 which drives the tappet at a time approximately corresponding to the exhaust and compression strokes in normal rotation of the engine (namely intake and explosion strokes in reverse rotation of the engine), and a cylindrical segment 106 connecting the segment 102 to the segment 104.

The cam 111 for the exhaust valve 32 is represented in Figs. 20 to 22 as approximately the same shape as the cam 101 for the inlet valve 31 but is of course different therefrom as to the time it starts driving the co-acting tappet. The cam 111 comprises a normally rotating engine action segment 112, a normally rotating compressor action segment 113 which drives the tappet at a time approximately corresponding to the exhaust and compression strokes in engine action, a reversely rotating engine action segment 114 which drives the tappet at a time approximately corresponding to the intake stroke in normal rotation of the engine, a reversely rotating compressor action segment 115 which drives the tappet at a time approximately corresponding to intake and explosioin strokes in normal rotation of the engine (namely exhaustion and compression strokes in reverse rotation of the engine), and a cylindrical segment 116 connecting the segment 112 to the segment 114.

The cam shaft 99 having the driving cam 91 for the valve 83 is provided separately from the cam shaft 109 having the cam 101 for the intake valve 31 and the cam 111 for the exhaust valve 32, each of the cam shafts being changed-over with axial sliding motion in five stages by hydraulic or electric shaft change-over means.

Upon starting of normal rotation of the engine, the tappets of the valves 83, 31 and 32 are brought respectively in co-acting relationship with the starting segment 93 in co-acting relationship with the tappet. high pressure air at about 20-50 kg/cm^2 (or 8-16 kg/cm^2) flows into the air chamber through the air port 82 and the engine is started. Then by moving the cam 91 reversely so that the tappet and the cylindrical segment 92, are in co-acting relationship, the engine effects the usual engine action.

In order to make the engine act as a normally rotating compressor the cams 91, 101 and 111 are moved until the tappets and the residual air exhaust segment 94 and the compressor action segments 103, 113 are in co-acting relationship so that the four-stroke engine serves as a two-stroke air-compressor, and residual air at the same time is discharged from the air port 82 through the pipe 85.

In the case of rotating the engine rever-

sely, the normally rotating engine is changed over first into normally rotating compressor action and braked, and after the engine stops the cam shafts 99, 109 are moved until the tappits are in co-acting relationship with the reverse rotation starting segment 95 and the reversely rotating engine action segment 104, 114.

Also, in the case of returning the reversely rotating engine to normal rotation, the engine is first made to serve as a reversely rotating compressor.

In the abovementioned fourth embodiment in the case of an engine with five or more cylinders, an air port valve 83 of any one of the cylinders is opened when the cam shaft 99 is moved and set so as to work the air port 83 by means of the normal rotation starting segment 93, so that the chamber can be supplied with compressed air, thus making it easy to start the engine with compressed air.

However, in the case of an engine with four or less cylinders, and especially with a single cylinder, a piston sometimes stops at the top or bottom dead center, thus causing an air port valve to be closed.

Therefore, a decompression device (not shown) is provided for opening such a closed valve so as to make the engine take up an air motor action. In this case, the decompression device is not a device for pressure reduction but for pushing down a valve stem of the inlet valve to introduce air and for momentarily opening the air port valve of the engine set to effect an air motor action so as to compulsorily introduce compressed air into a chamber thus rotating a crank shaft. In the case that the said crank shaft rotates in the positive direction, the air port valve can effect a normal opening and closing operation so that the motor can immediately work as an air motor. On the contrary, in the case that the said crank shaft rotates in the reverse direction, said air port valve is opened during the time the piston is being raised and compressed air injected through inlet port causes the piston to be lowered, so that the rotaion of the crank shaft turns into the positive direction. Also in the case that the engine is set to effect reversely rotating operation, the engine if rotating undesirably in the normal direction will return to reverse rotation since the valve timing of the air port valve is disturbed.

In the case of an engine with two or four cylinders, a piston of one of said cylinders stops at the top dead centre and even when the piston stops there, the associated crank shaft can be rotated a little. But in the case of an engine with a single cylinder, the associated piston possibly stops at the bottom dead centre. Therefore, in the case of an engine with a single cylinder, it is preferred so to construct the engine that a small volume of low pressure compressed air can be injected through an air exhaust port of the associated crank chamber.

This urges the piston upwards, and a decompression device is operated once the piston has been displaced to the top dead centre.

The advantages of using an engine with the abovementioned construction in a ship are that a powerful braking of the engine can be achieved in a very short time by an air compression action of the engine, that the compression action of the engine is influenced only by the compression ratio thereof and prevented from becoming destructive by a cushioning effect of the air, and that, considering the possibility of further increasing the back pressure exerted on a piston, high pressure air compressed in two stages can be used for increasing the back pressure for a compression action of each cylinder, thus giving the possibility of rapidly bringing the speed of engine rotation close to zero. In such a case, for example, the first set of cylinders are changed over into the state for reversely rotating engine action and at the same time other cylinders, for example, the second set of cylinders, are supplied with compressed air and operated as a reversely rotating air motor, and then brought into a high speed rotation suddenly so as to effect a reversely rotating engine action. And then, the second set of cylinders will be effecting a reversely rotating engine action similarly to, and enhancing, the action of the first set. Such a variety of applications of an engine, which have been impossible with conventional engines known to the applicant, can be obtained according to some embodiments of the present invention.

After the engine is actuated and rotated by air, consumed compressed air has to be replaced in the tank. For this purpose, compressed air can be obtained by operating the second set of cylinders as an air compressor. In this case, however, only the residual compressed air in the second set is used for supercharging the first set.

According to an embodiment of the present invention, compressed air can be obtained by a variety of combinations of actions of a plurality of cylinders, so that the provision of an auxiliary compressor with a conventional engine can be dispensed with.

In the case that an auxiliary compressor is required for double safety, there can be attached to the main engine a normally and reversely rotatable combination engine and air compressor apparatus with a single cylinder or a plurality of cylinders as a starter, which has a suitable torque. Also

for this purpose, a second-hand engine can be used after reconditioning to bring it into accordance with an embodiment of the invention in case of applications in which it is not too frequently to be used. In particular, the reconditioning expense can be lowered by utilizing a petrol or mixture engine with double overhead cam shafts.

Further, particularly in the case of an engine with double cam shafts such as are described in said first embodiment, the engine can be changed over from one to the other of an engine action and an air compression action by providing respective cams for an engine action and for an air compression action on a cam shaft, and sliding said cam shaft similarly to the third embodiment. And with such an arrangement even an engine with a small number of cylinders can be easily operated as an air compressor, and at the same time the engine can be easily made subject to an interlocking operation with spring force adjusting means as described in specification 4479/74 (Serial No. 1466 311).

To sum up the advantages of the embodiments described:

(1) The double cam shaft engine can serve as an air compressor easily by changing the angular relationship between the crank shaft the cam shaft for the exhaust valves and rotating the two cam shafts at the same velocity as the crank shaft.

(2) The engine can be worked as an air compressor simply and easily by providing a special electromagnetic clutch for always providing a particular angular relationship on the cam shaft of the engine and an automatic exhaust valve on the cylinder head.

(3) While the vehicle is slowing down either to stop or during running of the vehicle, compressed air can be obtained by making a part or the whole of the engine serve as an air-compressor.

(4) While the vehicle is at rest, compressed air can be obtained continuously by making a part of the engine serve as an air-compressor while making the other part serve as an engine.

(5) An engine with an even number, e.g. four, six or eight cylinders, or with an uneven number of cylinders can be operated to make about half of the cylinders serve as an air-compressor or effect no-load operation during the vehicle's running, and thereby fuel consumption may be reduced and air pollution may be prevented.

(6) Since a plurality of cylinders may be divided into two sets, one for an engine action and the other for an air-compressor action, so that the air-compressor set may compress the air in two stages to a predetermined pressure upon starting of the engine set, compressive load can be made small so that the engine set can be easily started.

(7) Compressed air directly supplied from the tank and compressed air obtained after use in the compressed air machine are at extremely low temperatures and are therefore more effective when used for supercharging of the engine set, whereby even if the number of cylinders of the engine set is the same as that of the air-compressor set, the driving power of the engine set is increased and the air-compressor set can be easily started.

(8) Since air exhausted from the compressed air machine is not discharged into the atmosphere but led into the engine set through a pipe, the noise emission from the compressed air machine is substantially reduced.

(9) By supplying the air chamber with high pressure air through the third air port described, rapid starting of the engine with large torque can be effected, which allows increased effectiveness of driving ability.

(10) Since, upon reversal of rotary direction the engine is first braked, serving as an air-compressor, the rotary direction can be changed rapidly and kinetic energy of the engine can be used effectively.

(11) Change-over between normal and reverse rotation of the engine can be effected easily and simply by providing a driving cam for reverse rotation on each of the inlet valve, the exhaust valve and the air port valve for exhausting residual air, thus providing a device is applicable to all sorts of engines, whether large-sized or small-sized.

(12) Even an engine with four or less cylinders or a single cylinder can be started in normal or reverse rotation by providing suitable decompression means.

WHAT I CLAIM IS:—

1. A combination internal combustion engine and air compressor having at least one compression chamber able to operate in a first operating mode as a combustion chamber and in a second operating mode as an air compressing chamber for compressing air without admixture of fuel, and means comprising two transmissions between a crankshaft and one or respective valve timing camshafts of the combination, the transmissions being able to operate in a way in which they do not simultaneously interconnect the crankshaft with a common said cam shaft, there being in the combination a compressed air source and means for connecting the source operatively to at least one said chamber.

2. A combination as claimed in claim 1, wherein the connecting means can be put into a condition to enable compressed air to be used to start operation of the combination, with at least one said chamber in the first mode.

3. A combination as claimed in claim 1

or 2, wherein the connecting means can be put into a condition to enable compressed air to be used for supercharging of at least one said chamber.

4. A combination as claimed in claim 3, having a plurality of the chambers divided into two sets of which one set is connected so that it can be supercharged.

5. A combination as claimed in any preceding claim, wherein the connecting means can be put into a condition to enable compressed air to be used to operate at least one said chamber of the combination as an air motor.

6. A combination as claimed in any preceding claim, comprising at least two said chambers and wherein the said source is provided by at least one said chamber operating in the second mode.

7. A combination as claimed in any preceding claim, wherein said source is an inlet to the combination to receive compressed air from outside the combination.

8. A combination as claimed in any preceding claim, wherein the combination can be put in a condition in which one said transmission is effective to control valve timing in said first mode and the other transmission is ineffective to control valve timing in that mode.

9. A combination as claimed in any preceding claim, wherein the combination can be put in a condition in which one said transmission is effective to control valve timing in said second mode and the other transmission is ineffective to control valve timing in that mode.

10. A combination as claimed in any preceding claim, adapted to propel a vehicle and comprising one or more cylinders, a piston adapted to slide in each of the aforesaid chambers defined in said cylinders, an inlet valve and an exhaust valve for opening and closing an inlet port and an exhaust port respectively provided on the upper portion of each said cylinder, two cam shafts respectively comprising a cam for said inlet valve and a cam for said exhaust valve for operating said inlet valve and said exhaust valve respectively, a first transmission for transmitting rotation of a crank shaft to said two cam shafts, a means connected to said inlet port for supplying air with and without fuel thereto and a means connected to said exhaust port for guiding exhaust gas therefrom, an air take-out means for taking-out air compressed in the chambers through said exhaust port and storing said air, an operating means for operating said air supply means to supply air without fuel and said air take-out means at a desired time and a second transmission for rotating said cam shafts for said inlet and exhaust valves at the same velocity as said crank shaft thereby changing the valve-timings of said inlet and exhaust valves from the timings due to said first transmission, so that the engine effects operation in said first mode when said two cam shafts are rotated by the first transmission and effects operation in said second mode when said two cam shafts are rotated by the second transmission.

11. A combination as claimed in claim 10, which comprises a changing means for changing the angular relationship of said cam shafts for said inlet and exhaust valves respectively with respect to said crank shaft so as to start the opening of said exhaust valve after 180° displacement in the cycle from the closing of said inlet valve, an automatic exhaust valve provided on the upper portion of cylinders, said air supply means being adapted then to supply air without fuel to the cylinders through said inlet and exhaust ports, said air take-out means being adapted to take out air compressed in the chambers by operating said automatic exhaust valve and storing said air and said operating means being adapted to operate said changing and transmission means, said air supply means and said air take-out means at the same desired time.

12. A combination as claimed in claim 10 or 11, which comprises a means for effecting and releasing connection between said crank shaft and one of said transmissions, including a clutch means for transmitting rotation of said crank shaft to each of said cam shafts with a predetermined angular relationship different from that in said first mode, a means for effecting and releasing connection between the crank shaft and the other of said transmissions and a means for dividing each of said cam shafts into separately rotatable portions.

13. A combination as claimed in claim 11 adapted in said second mode for air to be sucked into the chamber by opening both of the inlet and exhaust valves during the time corresponding to suction and explosion steps of said first mode action and for air to be exhausted by operating an automatic exhaust valve during a later part of the times in the second mode action corresponding to compression and exhaust strokes of said first mode action.

14. A combination as claimed in any one of claims 1 to 9, comprising a plurality of cylinders disposed in a casing, a piston adapted to slide in each of the aforesaid chambers defined in said cylinders, an inlet and an exhaust valve for opening and closing an inlet and an exhaust port respectively provided on the upper portion of each of said cylinders, cam shafts each comprising cams for said inlet and exhaust valves of respective cylinders for operating said inlet and exhaust valves, a means connected to said inlet port for supplying air

with and without fuel thereto and a means connected to said inlet port for supplying air with and without fuel thereto and a means connected to said exhaust port for guiding exhaust gas therefrom, passages associated with the cylinder respective to each cam shaft which thereby form first and second sets each comprising one or more cylinders, said second set being provided with an air supply means for supplying air without fuel and an air take-out means for taking out air compressed in said cylinders of the second set at a desired time and supplying the same at a desired pressure to the inlet port of the cylinder/s of said first set.

15. A combination as claimed in claim 14, in which said first set of cylinders are adapted to operate in said first mode by arranging to supply them with air and fuel, when said second set of cylinders are adapted to operate in said second mode by arranging to supply them with air without fuel.

16. A combination as claimed in claim 14, in which said cam shaft of said first set is provided with cams for inlet and exhaust valves each comprising a normal cam portion with an increased valve overlapping angle, said cam shaft of said second set is provided with cams for inlet and exhaust valves, said cam for an inlet valve of said second set is provided with a normal cam portion for operation in the first mode and an axially elongated cam portion for operation in the second mode adapted to open and close the inlet valve twice per rotation of the cam shaft, said cam for an exhaust valve of the second set is provided with a normal cam portion for operation in the first mode, a 1-step compression action portion adapted to open and close the exhaust valve twice per rotation of the cam shaft in operation in the second mode, a 2-step compression action portion and a no-load operation portion adapted to overlap opening and closing of the inlet valve and that of the exhaust valve, there are means for introducing exhaust gas from said second set of cylinders into other cylinders, and each of the cam shafts of said first and second sets is provided with means for axially displacing the cam shafts.

17. A combination as claimed in claim 14, in which an exhaust pipe of said second set of cylinders of the engine is connected to an inlet port of a compressed air machine, and an exhaust port of said compressed air machine is connected through a pipe to an inlet pipe of said first set of cylinders of the engine.

18. A combination as claimed in any one of claims 1 to 9, adapted to propel a vehicle and in which a plurality of cylinders defining said chambers are divided into first and second sets, and at least said second set is adapted to operate in said second mode, there are means for supplying chambers of said second set with compressed air so as to start the vehicle by air and fuelling said first set so as to operate in said first mode at the time of starting of the vehicle, for fuelling said first and second sets at times of acceleration and high speed travelling of the vehicle so as to obtain operation of both sets in said second mode for allowing said second set to draw without fuel during idle operation and cruising operation so as to obtain no-load operation of said second set, and for supplying at least said second set with air without fuel at times of deceleration so as to obtain an air compression action whereby to tend to reduce the speed of the vehicle and produce compressed air.

19. A combination as claimed in anyone of claims 1 to 19, which includes an air port provided separately from inlet and exhaust ports on a said chamber, a manifold connected to said air port, a passage of which is divertible through a valve and a branch pipe of which is connected through a passage opening and closing valve to a tank for storing compressed air, an air port valve for opening and closing said air port, a cam shaft comprising a cam for operating said air port valve so as to inject compressed air through said air port into the chamber and a displacing means for axially displacing said cam shaft, each of said cams for said inlet and exhaust valves being provided with a cam portion for normal rotation and a cam portion for reverse rotation of the crankshaft.

20. A combination as claimed in claim 19, in which each of said cams for said inlet valve and said exhaust valve is provided with a said first mode action segment and a said second mode action segment each for normal rotation, and another first mode action segment and another second mode action segment each for reverse rotation, and said cam for said air port is provided with an starting action segment and a compression action segment each for normal rotation, another starting action segment and another compression action segment each for reverse rotation, and a closing segment for keeping the air port closed during operation in the first mode.

21. A combination internal combustion engine and air compressor, substantially ac-

cording to any embodiment hereinbefore described with reference to the accompanying drawings.

22. A vehicle comprising a combination as claimed in any preceding claim.

23. A method of compressing air wherein there is used a combination or vehicle as claimed in any preceding claim.

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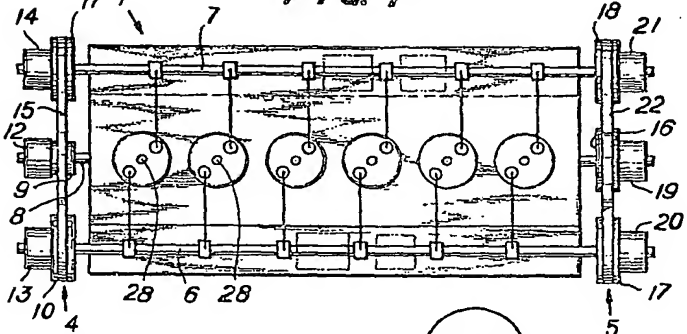
7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 1

FIG. 1



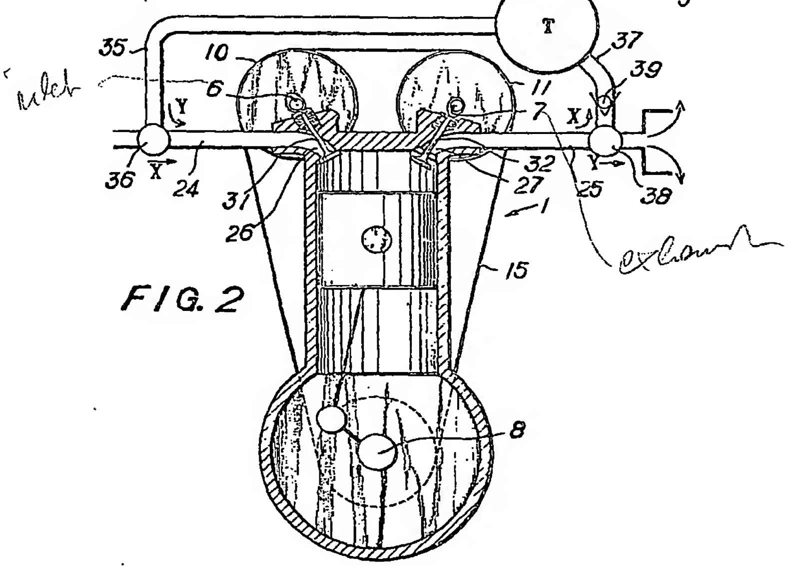


FIG. 2

automatic exhaust valve

air tank

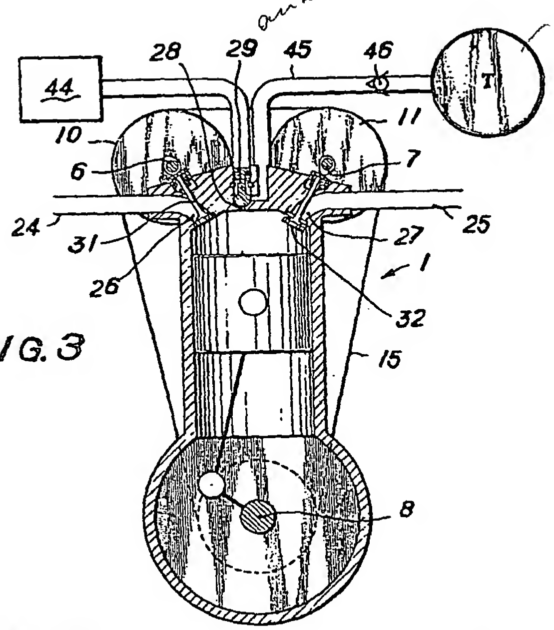


FIG. 3

FIG. 5

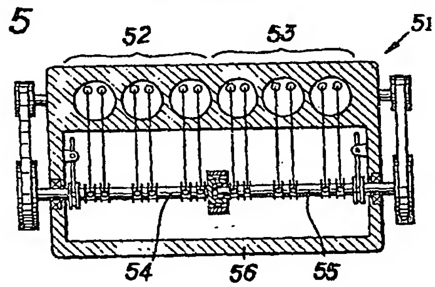


FIG. 4

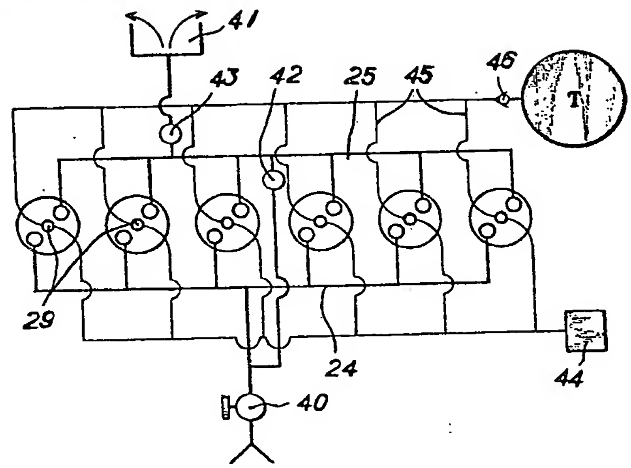


FIG. 6

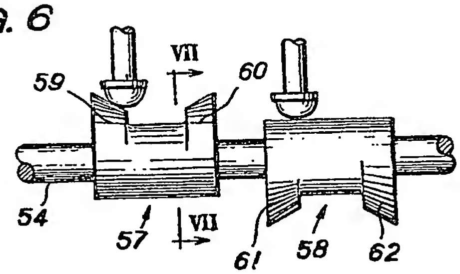


FIG. 7

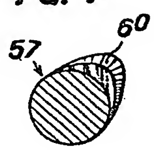


FIG. 8

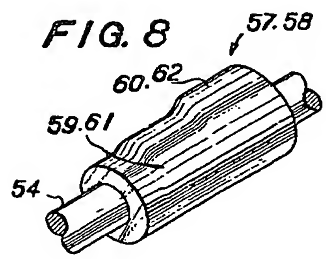


FIG. 9

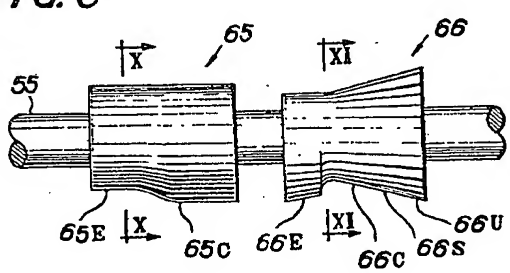


FIG. 10

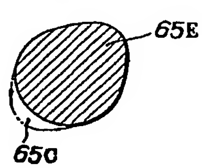
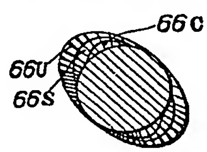


FIG. 11



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Sheet 5

FIG. 12

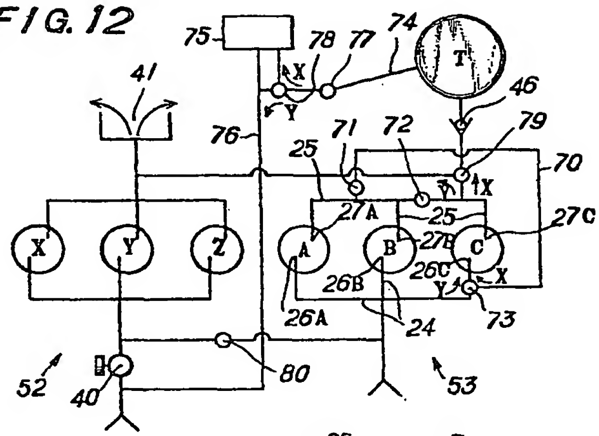
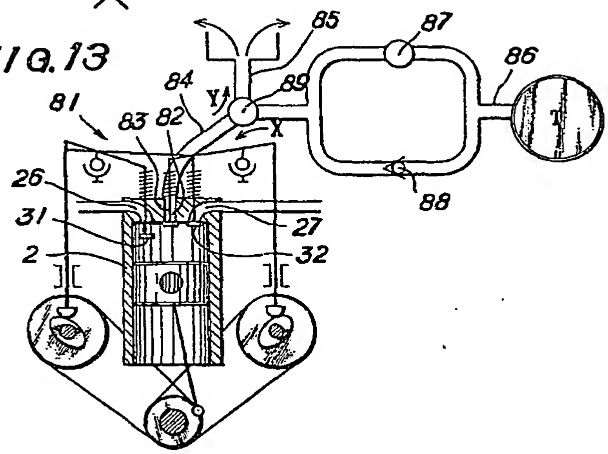


FIG. 13



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Sheet 6

FIG.14

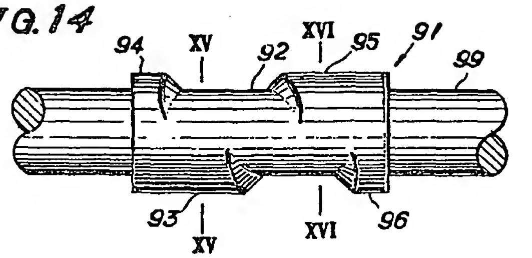

FIG.17

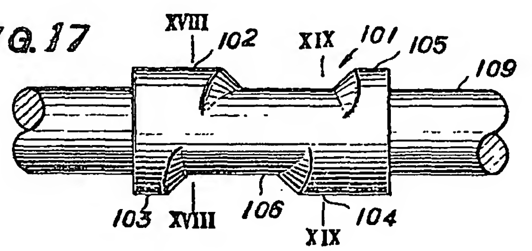

FIG.20

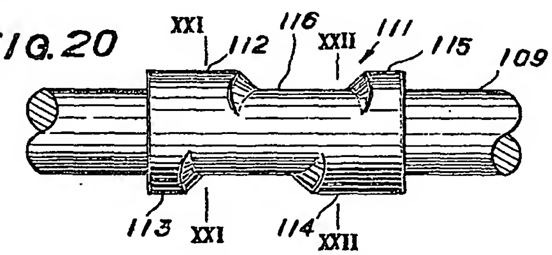

FIG. 15

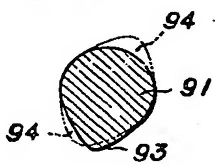

FIG. 16

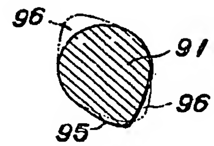

FIG. 18

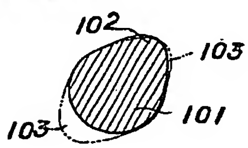

FIG. 19

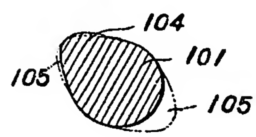

FIG. 21

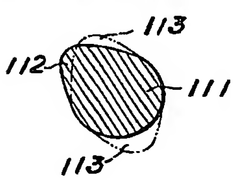

FIG. 22